The latest update on individual external doses in an early stage after the Fukushima nuclear accident

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Short running title: Update on external doses after Fukushima

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Abstract

Following the Fukushima Dai-ichi Nuclear Power Plant accident, a survey for estimating individual external doses for the first four months after the accident was started and it remains ongoing. Since the authors' previous paper, 44,605 new dose estimates have been made. The new dose estimates increase the number of dose estimates to 465,999 and are reported in this note. Since the previous paper, most of the recently collected responses have been gotten through public relations activities to encourage responses across the prefecture. Thus, recent respondents might be biased ("selection bias"). Also, the dose estimates were based on self-administered responses about personal behavior, which relied on memories of residents. In this respect, incorrect behavior records possibly resulted as memories have faded over time ("recall bias"). However, the effects of these biases on dose distribution on a whole-prefecture basis seemed to be small.

INTRODUCTION

Following the Fukushima Dai-ichi Nuclear Power Plant accident in 2011, the Fukushima Prefectural Government and Fukushima Medical University started the Fukushima Health Management Survey (FHMS). As a part of the FHMS, a survey (called the "Basic Survey") for estimating individual external doses in an early stage after the accident was also started and its results have been previously reported [(1)].

The Basic Survey is a self-administered questionnaire survey that asks people to record and send back information on their behavior in the 4 months after the accident. The Basic Survey targets people who were registered as residents of Fukushima Prefecture from March 11 to July 1, 2011 (around 2 million people). Behavior records of Basic Survey respondents were digitalized, and individual estimates of external exposure were made using daily ambient dose rate maps and a calculation program. As of June 30, 2014, the four-month dose had been estimated for 421,394 people (excluding radiation workers) [(1)].

One aspect of the Basic Survey has been to provide radiation dose estimates in the early stages after the accident for residents of Fukushima Prefecture who wanted this dose information [(2)]. There are still people who want information on their doses but need support to fill in the questionnaire. Thus, various activities to encourage responses were conducted even after the previous report was published [(3)]. Work for estimating individual doses and delivering the dose information to respondents is still ongoing, whenever questionnaire responses are received from residents.

For this reason, more than 40,000 new dose estimates have been made since the previous paper. The latest update of dose estimates is reported in this note.

MATERIALS AND METHODS

The study protocol of the Basic Survey was reviewed and approved by the Ethics Review Committee of Fukushima Medical University. The method for dose estimation is described in detail in the previous paper [(1)]. After the questionnaires are sent back, the behavior records are digitized so they can be processed by the dose calculation program. The program used for dose calculation remains the same as reported in the previous paper.

Among the responses, there were some for which records of behavior data covered less than four months for various reasons. Although individual doses were estimated for those responses, the estimation was intended mainly to inform respondents of their individual doses rather than further analysis. Such responses and resulting doses are excluded in the following discussion.

RESULTS

The previous paper reported the four-month individual doses estimated for 421,394 respondents as of June 30, 2014. After that, a total of 44,605 dose estimates were added until March 31, 2019, resulting in a total of 465,999 dose estimates. Figure 1 shows the seven areas of the prefecture and Table 1 summarizes the distribution by area for the dose estimates. Here, as in the previous paper, dose estimates for radiation workers were excluded.

The latest dose distribution as of March 31, 2019 was almost the same as reported in the previous paper. It was: 62.2%, < 1 mSv; 93.9%, < 2 mSv; 99.4%, < 3 mSv, while the previous distribution was: 62.0%, < 1 mSv; 94.0%, < 2 mSv; 99.4%, < 3 mSv.

However, the maximum doses were updated for two areas. The maximum doses for Kenchu and Aizu were updated from 5.9 to 10 mSv and 3.6 to 6 mSv, respectively. The respondents corresponding to the updated maximum doses were registered residents for the two areas at the time of accident, but they entered evacuation zones around the power station (in Soso area, Figure 1) after the accident for various reasons, which increased their external doses.

Table 2 compares the distribution of dose estimates reported in the previous paper (as of June 30, 2014) with that of newly added dose estimates (columns (A) and (B)). Both distributions were similar. Table 2 also includes dose distribution as of June 30, 2015 [4, 5] and added dose estimates after that (columns (C), (D) and (D')). These are discussed later.

The distribution of estimated external doses by age groups presented in the previous paper [1] was updated as Table 3. As shown in the last row of Table 3, most of the new dose estimates came from respondents younger than 20. It is mainly due to the activities to encourage responses at venues for a thyroid ultrasound examination, which mainly targets residents younger than 18 at the time of the accident [3]. As shown in Table 3, differences in dose distribution between age groups were not large.

DISCUSSION

An analysis of representativeness was previously conducted for 454,940 dose estimates completed until June 30, 2015 (column (C) in Table 2) [4, 5]. Even if the response rate was only about 27% for the entire prefecture, the dose distributions obtained were representative of all Fukushima residents. There were no significant differences in estimated doses between respondents and non-respondents in the same areas. From June 30, 2015 until March 31, 2019 (column (D) in Table 2) 11,059 dose estimates were newly completed. Most of the responses collected during this period resulted from the activities to encourage responses across the whole prefecture [3].. A selection bias [6] could occur for two reasons: (1) more efforts were made to encourage younger respondents as described before and (2) public relations activities were not carried out uniformly throughout the prefecture. However, regarding the first point, the dose dependence on age was small as shown in Table 3, so this selection bias might accordingly be small. The second selection bias could be corrected in the following way. The area distribution of dose estimates was different between columns (C) and (D) in Table 2, as shown in Table 4 (see ratio by areas in the last row of each table part). For example, the ratio of dose estimates in the Kempoku area to the total estimates was 27.1% for column (C) in Table 2, although it was 14.3 % for column (D) in Table 2. Thus, the area distribution of column (D) was corrected so that it could to be the same as column (C). For example, the number of dose estimates with effective doses less than 1 mSv in the Kempoku region was corrected by dividing 160 (first row in the lower part of Table 4) by (14.3/27.1=0.529), which resulted in the corrected number, 303.

After the same correction was applied to other dose bands and areas, and the numbers for each dose band were summed, the percentages of newly added dose estimates (11,059) were: 58.4% for doses less than 1 mSv; 33% for doses 1-2 mSv; and 7.6% for doses 2-3 mSv (column (D') in Table 2). After such an adjustment, the distribution of the added dose estimates (column (D')) was similar to column (C) in Table 2.

There was also a possible second bias ("recall bias" [6]) in which memories have faded as time has passed. In this case, the dose estimates were based on self-administered responses on personal behavior after the accident and the behavior records relied on memories of residents. An approach to check its effects on dose estimation might be to ask residents who have already responded to submit a new response to compare their doses. However, care and support for residents should be a higher priority after the

Fukushima accident. Considering this situation, asking for a new response for those who have already responded is not feasible. Since the dose distribution based on recently collected responses was similar to that previously estimated (Table 2), the effect of recall bias on dose estimation was not likely to be important, as far as could be seen from the dose distribution.

The dose estimates by the Basic Survey are stored in a database, but information on the date of completing dose estimate has not been correlated with each dose estimate in the database. At present, the number of dose estimates included in each 1mSv-step can be extracted from the database by specifying a period of completing dose estimates (e.g., dose estimates completed up to June 30, 2014, as shown in Table 2 (A)). However, individual values of dose estimates (e.g., resident ID1, 1.0mSv; ID2, 1.5mSv; and so on) cannot be extracted by specifying the period of completing dose estimates.

The database will be improved in the future to allow extraction of individual dose estimates with information on when their dose estimates were done. When the improvement of database is finished, further analysis including statistical analysis (e.g., comparison of distribution between (A) and (B) in Table 2) will be done.

CONCLUSION

The individual dose distribution estimated for the first four months after the Fukushima accident remained the same as previously reported, although 44,605 dose estimates were newly added to the previous data. Considering that most of the recent responses resulted from encouragement activities and that the dose estimation was based on self-administered questionnaires, selection bias and recall bias may affect the dose distribution.

However, the effect seems to be small, as far as it could be seen from the dose distribution for recently collected responses.

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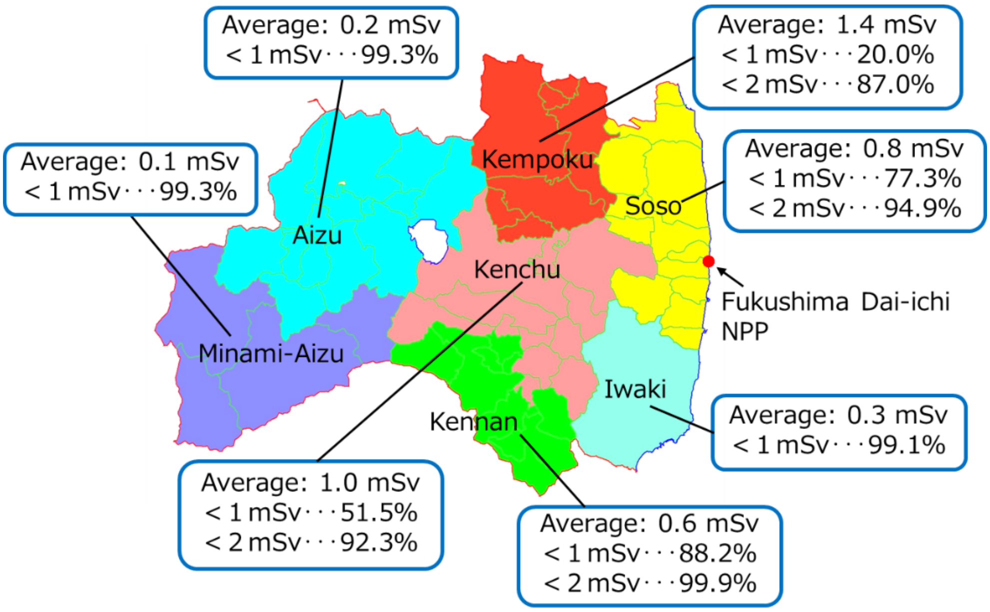

Figure 1. Locations of the seven areas of Fukushima Prefecture
(The white central area is Lake Inawashiro)

Table 1. The latest update for external dose distribution by areas

Effective dose (mSv)	Number of doses by areas (excluding those of radiation workers)							Total	
	Kempoku	Kenchu	Kennan	Aizu	Minami-Aizu	Soso	Iwaki	Number	Ratio (%)
<1	24,949	58,462	26,306	46,002	4,974	55,865	73,386	289,944	62.2
1-2	83,797	46,361	3,498	311	37	12,701	637	147,342	31.7
2-3	15,706	8,270	18	25	0	1,690	30	25,739	5.5
3-4	472	428	0	1	0	597	4	1,502	0.3
4-5	40	5	0	0	0	459	1	505	0.1
>5	32	5	0	1	0	928	1	967	0.2
Total	124,996	113,531	29,822	46,340	5,011	72,240	74,059	465,999	100
Maximum dose (mSv)	11	10	2.6	6	1.9	25	5.9	-	-
Average dose (mSv)	1.4	1	0.6	0.2	0.1	0.8	0.3	-	-

Table 2. A comparison between previously reported dose distributions and dose distributions based on newly added responses

Effective dose (mSv)	(A) As of June 30, 2014 [1]		(B) Increment from June 30, 2014 to Mar.31, 2019		(C) As of June 30, 2015 [5]		(D) Increment from June 30, 2015 to Mar.31, 2019		(D') Corrected for area distribution of increased dose estimates	
	Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)
<1	261,140	62.0	28,804	64.6	282,227	62.0	7,717	69.8	6459	58.4
1-2	134,848	32.0	12,494	28.0	144,636	31.8	2,706	24.5	3650	33.0
2-3	22,600	5.4	3,139	7.0	25,169	5.5	570	5.2	841	7.6
3-4	1,382	0.3	120	0.3	1,470	0.3	32	0.3	48	0.4
4-5	494	0.1	11	0.0	495	0.1	10	0.1	18	0.2
>5	930	0.2	37	0.1	943	0.2	24	0.2	43	0.4
Total	421,394	100.0	44,605	100.0	454,940	100.0	11,059	100.0	11,059	100.0

Table 3. The latest update dose distribution by age groups

Effective dose (mSv)	Number of doses by age groups (excluding those of radiation workers)									Total
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-	
<1	48,223	45,065	21,423	34,385	28,730	32,895	36,334	25,735	17,154	289,944
1-2	23,053	21,785	10,173	18,355	16,692	18,554	19,497	12,293	6,940	147,342
2-3	6,484	4,282	1,142	2,349	2,250	2,972	3,424	1,996	840	25,739
3-4	253	160	81	158	153	230	233	164	70	1,502
4-5	19	47	35	39	75	95	81	76	38	505
>5	24	31	55	81	105	226	203	165	77	967
Total	78,056	71,370	32,909	55,367	48,005	54,972	59,772	40,429	25,119	465,999
Added since the previous paper	12,078	13,034	2,768	4,573	3,384	3,096	3,208	1,913	551	44,605

Table 4 Detailed area distributions for columns (C) and (D) shown in Table 2.

Area distribution for column (C)

Effective dose (mSv)	Number of doses by areas (excluding those of radiation workers)							Total	
	Kempoku	Kenchu	Kennan	Aizu	Minami-Aizu	Soso	Iwaki	Number	Ratio (%)
<1	24,789	56,569	24,846	43,955	4,771	55,298	71,999	282,227	62.0
1-2	82,689	45,269	3,320	298	34	12,402	624	144,636	31.0
2-3	15,397	8,050	17	25	0	1,650	30	25,169	5.4
3-4	464	417	0	1	0	584	4	1,470	0.3
4-5	40	5	0	0	0	449	1	495	0.1
>5	31	4	0	1	0	906	1	943	0.2
Total	123,410	110,314	28,183	44,280	4,805	71,289	72,659	454,940	100
Ratio by area(%)	27.1	24.2	6.2	9.7	1.1	15.7	16.0	-	100

Area distribution for column (D)

Effective dose (mSv)	Number of doses by areas (excluding those of radiation workers)							Total	
	Kempoku	Kenchu	Kennan	Aizu	Minami-Aizu	Soso	Iwaki	Number	Ratio (%)
<1	160	1,893	1,460	2,047	203	567	1,387	7,717	69.8
1-2	1,108	1,092	178	13	3	299	13	2,706	24.5
2-3	309	220	1	0	0	40	0	570	5.2
3-4	8	11	0	0	0	13	0	32	0.3
4-5	0	0	0	0	0	10	0	10	0.1
>5	1	1	0	0	0	22	0	24	0.2
Total	1,586	3,217	1,639	2,060	206	951	1,400	11,059	100
Ratio by area(%)	14.3	29.1	14.8	18.6	1.9	8.6	12.7	-	100